

Simulation techniques for design of overhead conductor rail lines for speeds over 140 km/h

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In overhead conductor rail lines, aluminium beams are usually mounted with support spacing between 8 and 12 meters, to limit the maximum vertical deflection in the center of the span. This small support spacing limits the use of overhead conductor rail to tunnels, therefore it has been used almost exclusively in metropolitan networks, with operation speeds below 110 km/h. Nevertheless, due to the lower cost of maintenance required for this electrification system, some railway administrations are beginning to install it in some tunnels on long-distance lines, requesting higher operation speeds [1]. Some examples are the Barcelona and Madrid suburban networks (Spain), and recent lines in Turkey and Malaysia. In order to adapt the design of the overhead conductor for higher speeds ($V > 160$ km/h), particular attention must be paid to the geometry of the conductor rail in critical zones as overlaps, crossings and, especially, transitions between conductor rail and conventional catenary, since the use of overhead conductor rail is limited to tunnels, as already mentioned. This paper describes simulation techniques developed in order to take into account these critical zones. Furthermore, some specific simulations results are presented that have been used to analyze and optimizes the geometry of this special zones to get a better current collection quality, in a real suburban network. This paper presents the work undertaken by the Railways Technology Research Centre (CITEF), having over 10 years of experience in railways research [1-4].

SIMULATION TECHNIQUES FOR DESIGN OF OVERHEAD CONDUCTOR RAIL LINES FOR SPEEDS OVER 140 KM/H

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1. INTRODUCTION

In overhead conductor rail lines, aluminium beams are usually mounted with support spacing between 8 and 12 meters, to limit the maximum vertical deflection in the center of the span. This small support spacing limits the use of overhead conductor rail to tunnels, therefore it has been used almost exclusively in metropolitan networks, with operation speeds below 110 km/h.

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This paper describes simulation techniques developed in order to take into account these critical zones. Furthermore, some specific simulations results are presented that have been used to analyze and optimizes the geometry of this special zones to get a better current collection quality, in a real suburban network. This paper presents the work undertaken by the Railways Technology Research Centre (CITEF), having over 10 years of experience in railways research [1-4].

2. MODELING CHARACTERISTICS

Simulation models were defined combining finite element calculation and multibody systems dynamic simulation techniques. As explained in [1], for every model, the modelization process mainly consists on:

- First of all, a finite element model of every section of catenary is made using ANSYS software, taking into account the material elastic properties, geometry, etc. During this step, the stiffness matrix, nodes position, and frequency modes are obtained for every stretch.
- With this information and using the correct software tool, the matrices are introduced into a multibody simulation software SIMPACK model. In this multibody model, different bodies represent the different sections or stretch of catenary and the displacements of every node are solved by modal superposition of the frequency modes of the corresponding section.
- Finally, the model of the pantograph is added to the main model and the contact elements are created between the catenary and the pantograph.

Some specific characteristics of the modeling process are described in the next paragraphs.

2.1. Overhead conductor rail

For the whole simulations carried out, the overhead conductor rail cross section has been the standard one (110 mm height). The contact wire cross section has an area of 150 mm².

In the finite elements model, mainly three kind of elements have been considered:

- *Conductor rail and contact wire*: The conductor rail grips the contact wire with such force that all the forces are shared between both, which means that the wire contributes with its entire section to the rigidity of the set. This set has been modelled as a single body, for which the geometric properties (area, centroid, geometric moments) associated with an equivalent aluminium section, have been calculated.

- Conductor rail, contact wire and bridle: The geometric parameters for these sections are determined by adding the previous parameters to the ones for the bridle connector.
- Elastic supports: modeled as a vertical stiffness.

The specific modeling characteristics for the singular zones are explained in the next paragraphs:

a) Overlapping geometry

For the simulations made in this work, an overhead conductor rail model was used considering two straight sections. A section contains a nominal support spacing zone, a parameterized support spacing zone near the overlap, and a overlapping span. The next figure shows a section containing one staggering wave in the nominal spacing zone.

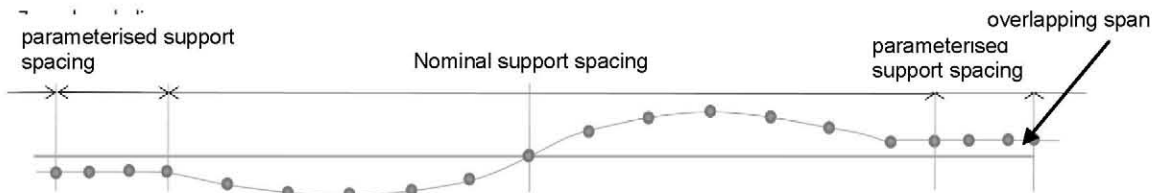


Figure 1

The overlapping geometry can be seen in the next figure and it was simulated according to the project design. It has a length of 2 m.

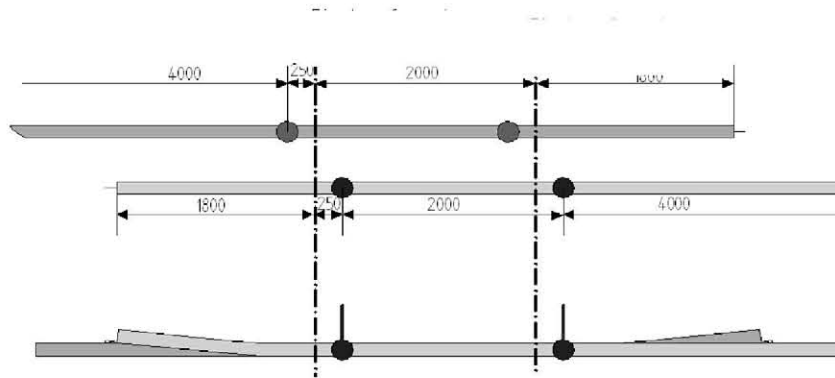


Figure 2: Plant and lateral views of the overlapping span

In particular, in the overlapping zone, support spacing and radius of curvature of the conductor rail in the vertical plane were optimized, in order to prevent contact losses between pantograph and contact wire, so ensuring a good current collection quality. For this purpose, distances L1, L2 and L3 (figure 3) have been parameterized in order to find an optimal geometry.

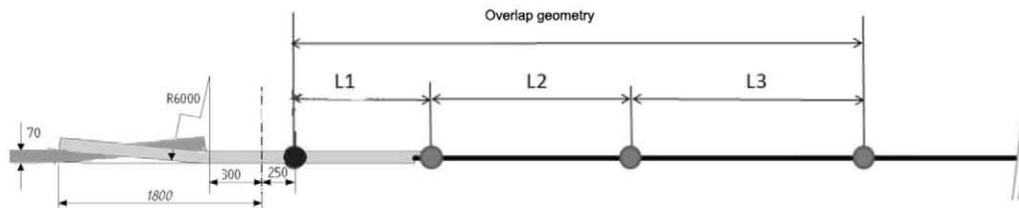


Figure 3: Overlapping zone geometry

b) Crossings geometry

In the case of the crossing model, an overhead conductor rail model was created considering four stretches, as can be observed in the next figure. In the overlaps between the stretches the same modeling techniques have been used as in the overlapping zones, taking into account the specific geometry of the crossing.

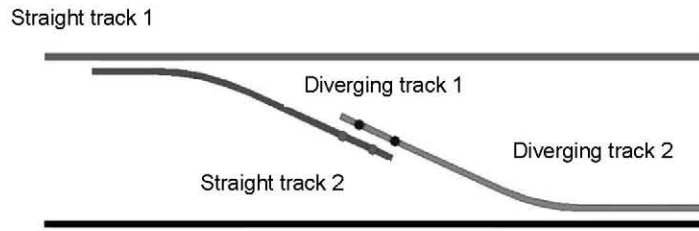


Figure 4: Crossing geometry outline

For the dynamic simulations carried out with this model, specific crossing data have been used, being the aim of the study, the analysis of the current collection quality for same circulation speeds

c) Transition modeling

The transition model has two straight sections too. The first section considers the overhead conductor rail with the a nominal spacing between supports. The second one, contains a transition piece (variable elasticity) and some conventional catenary spans.

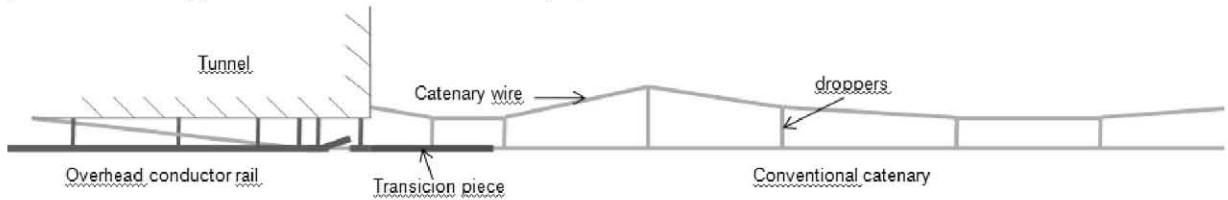


Figure 5: transition between overhead conductor rail and conventional catenary

Regarding the transition model, the next steps and simplifications have been considered:

- For this model staggering is not included. (2D model)
- The transition piece and the conventional catenary have been modeled using beam elements with variable section properties.
- A longitudinal force has been applied at the end of the stretch in order to consider the correct geometric stiffness of the conventional catenary stretch.

2.2. Pantographs modeling

Three pantographs types have been considered: metropolitan, suburban and high-speed. The modeling process is different for every model depending on the data. In some cases, a three lumped mass model has been used and in other cases a 3D model has been created starting from the components of the pantograph, as can be observed in the next figure.

The 3D model have 4 degree of freedom, including the roll and pitch of the pantograph head.

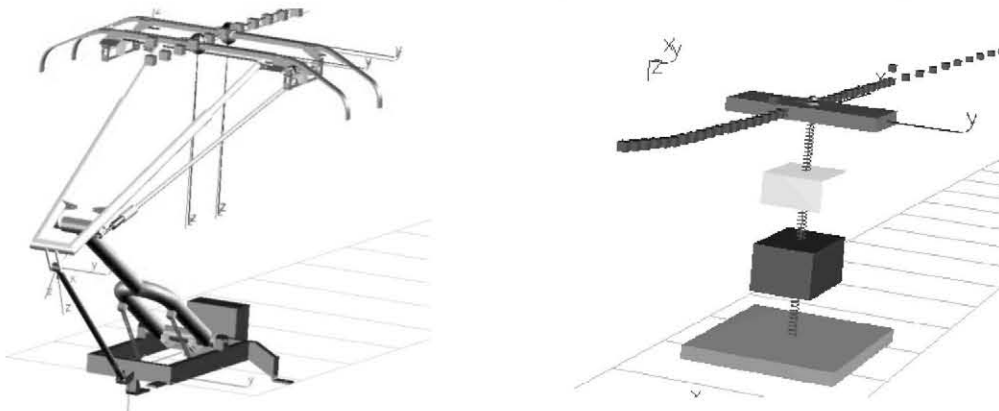


Figure 6: Two pantograph models: a) 3D model, b) equivalent three lumped mass model

2.3. Pantograph-catenary interaction

Finally the overhead conductor rail modeled in ANSYS, are exported into the pantograph model in SIMPACK. Afterwards, contact elements between pantograph and conductor rail have been created.

3. CRITERIA FOR ASSESSING CURRENT COLLECTION QUALITY

European railway administrations agreed to assess current collection quality by statistically processing the contact force between the catenary and the pantograph [5] and [6], while taking the following parameters into account:

- Mean value of the contact force, F_m ;
- Standard deviation of the contact force, σ ;
- Statistical minimum, $(F_m - 3\sigma)$;
- Statistical maximum, $(F_m + 3\sigma)$, which must not exceed a certain safety limit;
- Number of contact losses lasting more than 0.01 s;
- Total accumulated contact loss time.

Therefore, the main parameter used to assess current collection quality in this work is pantograph-catenary contact force.

4. RESULTS AT OVERLAPS

Three pantographs types were considered: metropolitan, suburban and high-speed. As the worst results were obtained for the suburban pantograph (see figure 7, red curve), this pantograph model was chosen to optimize the conductor rail geometry.

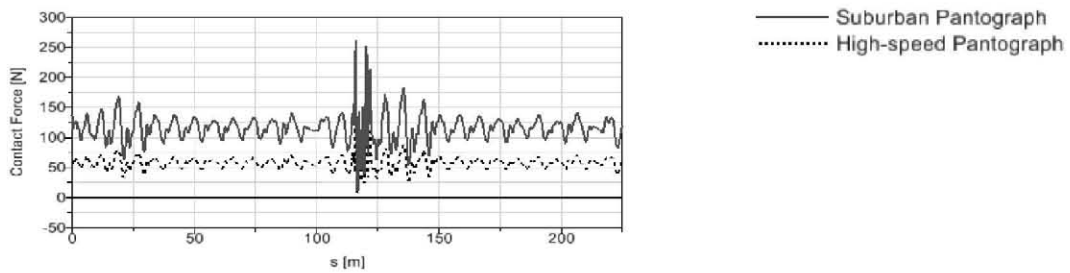


Figure 7: Contact force for different pantograph models

With the chosen pantograph, several simulation were performed modifying the overlap geometry. From the simulation results an optimal simulation was found, this being finally used in a real suburban network, with proven satisfactory behavior. As an example, table 1 compares two of the different overlapping geometries analyzed, A and B.

Overlapping geometry	$F_{c_{mean}}$ [N]	$F_{c_{Standard\ deviation}}$ [N]	$F_{c_{max}}$ [N]	$F_{c_{min}}$ [N]
A	115	22.7	183.1	46.9
B	115.25	27.25	197	33.5

Table 1: Contact force results for two different overlap geometries

For the best solution, several simulations were performed with both 10 and 8 m nominal support spacing, for speeds up to 100 km/h and over 120 km/h respectively. Figure 3 shows the contact force obtained for 10 m support spacing.

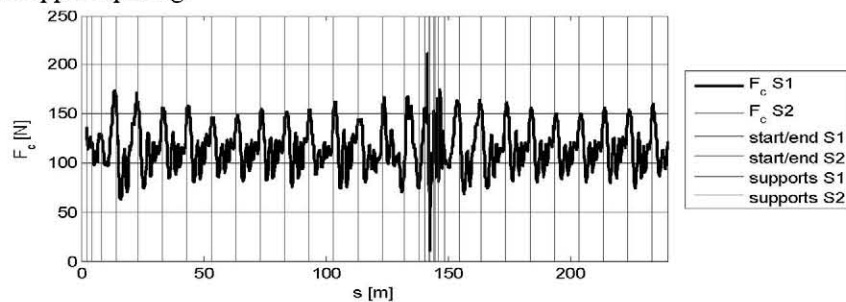


Figure 8: Total contact force in both sections considering the overlap zone

Table 2 shows the results obtained for other higher speeds, and 10 m supports spacing.

Speed [km/h]	Overlap geometry	F_{c_mean} [N]	$F_{c_Standard\ deviation}$ [N]
100	A	115	22.7
120	A	115	20.8
140	A	115.7	27.05

Table 2: Contact force results at different speeds and 10 m supports spacing

Table 3 contains the results obtained 8 m supports spacing and for the best overlapping geometry found, A.

Speed [km/h]	Overlap geometry	F_{c_mean} [N]	$F_{c_Standard\ deviation}$ [N]
100	A		
120	A	115.7	21.19
140	A	115.7	27.05

Table 3: Contact force results at different speeds and 8 m supports spacing

In both cases, values are lower than limits proposed by the standards used as criteria.

5. RESULTS AT CROSSINGS

Apart from overlap sections, different geometries of crossings were also considered in this study. As an example, figure 9 and 10 shows the results obtained of an specific crossing simulated using real data.

This graphs correspond to a simulation with the suburban pantograph, at 60 km/h circulating by the diverging track and circulating by the straight track at 100 km/h in the inverse direction.

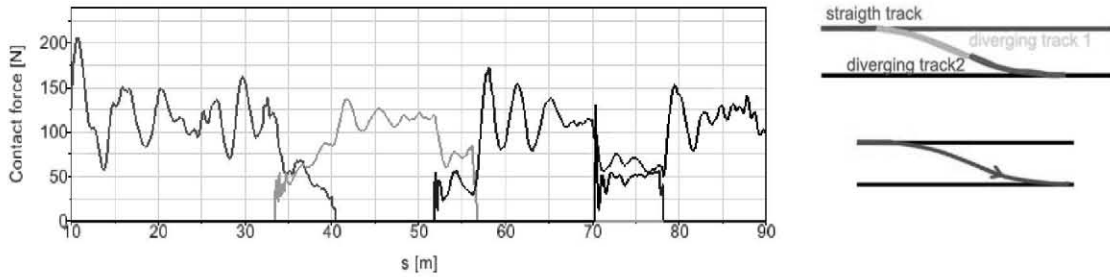


Figure 9: Contact force running through the diverging track at 60 km/h and direct direction

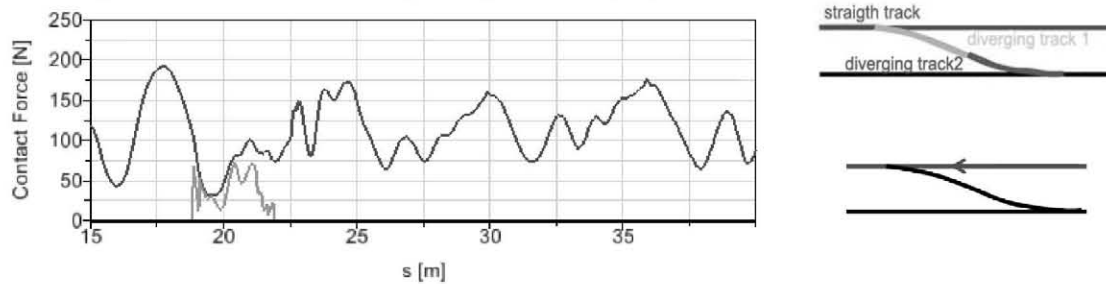


Figure 10: Contact force running through the straight track at 100 km/h and inverse direction

The standard deviation values for every track and direction are presented in the next table. The values for every scenery are below the limits, in correspondence with the standards.

Speed [km/h]	Track	Direction	$F_{c_Standard\ deviation}$ [N]
100	Straight	Direct	38.4
100	Straight	Inverse	34.2
60	Diverging	Direct	16.6
60	Diverging	Inverse	16.6

Table 4: Contact force results at crossing

6. RESULTS AT TRANSITIONS

Also simulations including transitions between overhead conductor rail and conventional catenary have been made. In this example, several simulations with a real transition were made in order to

find the maximum circulation speed. As an example the next figure shows the contact force of every section running at 90 km/h.

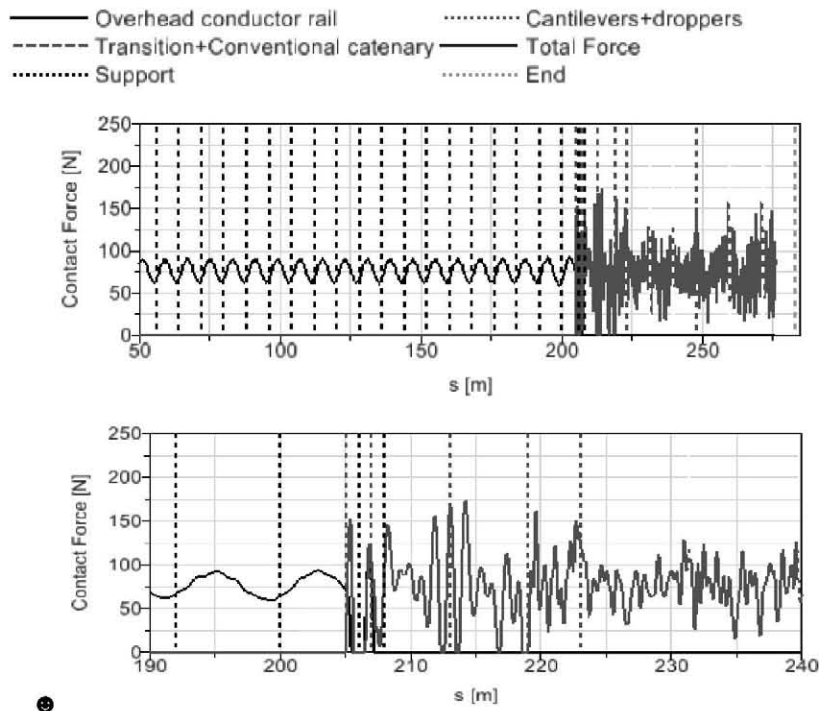


Figure 11: a) contact force at transition, b) detailed view of the transition zone

7. CONCLUDING REMARKS

Using the modeling techniques used in this work and exposed in this paper it is possible to model any overhead conductor rail geometry considering even critical zones such as overlaps, crossings, and transition between overhead conductor rail and conventional catenary.

These simulations can be used to analyze the current collection quality for an specific catenary system or even as an optimization tool in the design of a catenary system.

8. ACKNOWLEDGEMENTS

The authors want to acknowledge to ADIF, specially to Marcos Ania, the support offered for the development of the work presented in this paper.

9. REFERENCES

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